REMARKS/ARGUMENTS

Favorable reconsideration of this application in view of the above amendments and following remarks is respectfully requested.

Claims 10-26 are pending in this application. By this amendment, Claims 10-18 are amended; no claim is canceled; and Claims 19-26 are added herewith. Support for the present amendment may be found in the original specification, for example, at page 2, lines 3-11, at page 2, lines 18-22, at page 2, line 27 to page 3, line 2, at page 3, lines 9-12, at page 3, lines 27-28, at page 4, lines 2-9, at page 5, lines 8-9, in Figure 1, and in Claims 10-18. It is respectfully submitted that no new matter is added by this amendment.

In the outstanding Office Action, the specification was objected to; Claims 10-12 and 15-18 were rejected under 35 U.S.C. § 103(a) as unpatentable over Reiser (U.S. Patent No. 3,964,930, hereinafter "Reiser") in view of Fujita et al. (Japanese Patent No. JP 2002-238272 A, hereinafter "Fujita"); Claim 13 was rejected under 35 U.S.C. § 103(a) as unpatentable over Reiser in view of Fujita, and further in view of Ghamaty et al. (U.S. Patent No. 6,096,964, hereinafter "Ghamaty"); Claim 14 was rejected under 35 U.S.C. § 103(a) as unpatentable over Reiser in view of Fujita, and further in view of Szabo de Bucs et al. (U.S. Patent No. 3,470,033, hereinafter "Szabo de Bucs").

With respect to the objection to the specification, Applicants attached both clean and marked-up copies of the substitute specification with lines spaced 1½ lines apart on good quality paper. Further, the specification is amended to fix informalities by including section headings consistent with 37 C.F.R. § 1.77(b) and MPEP § 608.01. Under the new section heading "Brief Description of the Drawings" the related text is supported by the original specification at page 3, lines 27-28. As such, the changes to the specification do not raise a question of new matter. Accordingly, withdrawal of the objection to the specification is respectfully requested.

In response to the rejections under 35 U.S.C. § 103(a), Applicants respectfully request reconsideration of these rejections and traverse these rejections, as discussed below.

Regarding the rejection of Claim 10 as unpatentable over Reiser in view of Fujita, the claim recites, in part, "[a] fuel-cell stack, comprising: at least two elementary cells *in facing relationship*, [a] reactant and the oxidizer circulate within each elementary cell; [and] an internal duct formed *between* the cells."

The internal duct is used to carry cooling fluid between the two elementary cells. As described in the original specification, for example, at page 4, lines 2-6 and in Figure 1, the elementary cells can be composed of two bipolar plates separated by a porous membrane. The plates have engraved ducts for circulating oxygen and hydrogen. The internal duct is formed between the elementary cells for circulation of a cooling fluid and the two elementary cells are disposed in a facing relationship.[1]

It is respectfully submitted that the cited references do not disclose or suggest every feature recited in Claim 10.

Reiser describes a fuel-cell cooling system having fuel-cells 22, each comprising a cathode 26, an anode 28, and an electrolyte retaining matrix 30.[2] At one side of each fuel-cell 22, there may be a first type of separator plate 24a having cooler tubes 60 to carry a non-dielectric coolant and channels 32a, 34a for circulating an oxidant and a reactant respectively.[3]

However, it is respectfully submitted that Reiser does not disclose or suggest "[a] fuel-cell stack, comprising: at least two elementary cells *in facing relationship*, [a] reactant and the oxidizer circulate within each elementary cell; [and] an internal duct formed *between* the cells," as recited in Claim 10.

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[1] See original specification at page 2, lines 3-6.
[2] See Reiser at col. 3, line 59 to col. 4. line 6, and in Figure 2
[3] See Reiser at col. 4, line 19-23.

Instead, as discussed above, Reiser describes some of the functions necessary for the operation of the fuel-cell are to carry a reactant into communication with the anode electrodes 28 and to carry an oxidizer into communication with the cathode electrodes 26.[4] These oxidizer and reactant carrying functions, are provided in the separator plates 24, 24b for both of the adjacent fuel-cell reactions. As the functions of adjacent fuel-cells in a stack as discussed by Reiser are *intertwined* at a separator plate, then the adjacent fuel-cells cannot be in a facing relationship. Fujita discusses a thermoelectric element producing electricity, not the relationship between fuel-cells. Accordingly, Fujita does not cure the deficiencies of Reiser.

Alternatively, assuming *arguendo* that a "fuel-cell" is defined merely as the anode 28, the cathode 26, and the electrode retaining matrix 30, then Reiser does not discusses the reactant and the oxidizer circulating within each elementary cell because the channels 32, 32a, 34, 34a are outside the "fuel-cell." Fujita discusses a thermoelectric element producing electricity, not the circulation of an oxidizer or reactant within a fuel-cell.

Therefore, it is respectfully submitted that the combination of Reiser in view of Fujita neither discloses nor suggests every feature recited in Claim 10. Thus, it is respectfully requested that the rejections of Claim 10, and Claims 11-16 which are dependent thereon, as unpatentable over Reiser in view of Fujita be withdrawn.

Claim 11 recites, in part, "wherein the first end of the pair [of elements of two conductive materials of dissimilar nature] is connected with a conductive thermal contact to a bipolar plate of the heat source."

As described in the original specification, for example, at page 2, lines 8-11, each thermoelectric module may be comprised of a pair of elements of two conductive materials of dissimilar nature. A first end of each pair is in conductive thermal contact with the bipolar

[4] See Reiser at col. 3, line 68 to col. 4, line 6.

plate of the heat source and the other is in thermal contact with the internal duct of the cold sink.[5]

It is respectfully submitted that the cited references do not disclose or suggest every feature recited in Claim 11.

Fujiita describes a thermoelectric element based on n-type and p-type semiconductor materials which transforms thermal energy into electric power directly using the Seebeck effect.[6] Further, Fujita discusses that the electric power output of a solid oxide fuel-cell (SOFC) may be supplemented by using the thermoelectric element to extract energy from the heat of the exhaust gas discharged from the SOFC.[7] Fujita also mentions that the thermoelectric element may be applied to a heat exchanger connected to the exhausted gas from a SOFC.[8]

Reiser describes heat exchanger cooler elements 36, 38 for each fuel-cell stack 10, 12.[9] Each of the heat exchanger cooler elements 36, 38 have an inlet plenum 56 and an outlet plenum 58 which communicate with the cooler tubes 60 passing through the separator plates 60.[10] Reiser discusses the heater exchanger cooler elements are outside of the fuel exchanger stacks.[11]

However, it is respectfully submitted that neither Fujita nor Reiser disclose or suggest "the first end of the pair [of elements of two conductive materials of dissimilar nature] is connected with a conductive thermal contact to a bipolar plate of the heat source," as recited in Claim 11.

Instead, as discussed above, Fujita describes only a thermoelectric element applied to a heat exchanger used with the exhaust gases of a fuel-cell, and Reiser describes only a heat

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[5] See original specification, for example, in Figure 1.
[6] See Fujita, ¶ 3, English translation.
[7] See Fujita, ¶ 19, English translation.
[8] See Fujita, ¶ 25, English translation.
[9] See Reiser, at col. 3, line 59 to col. 4, line 34.
[10] See Reiser, at col. 4, lines 54-57.
[11] See Reiser, Figures 1-2.

exchanger for coolant outside of the fuel-cell stack. The Office Action on page 5, lines 3-6 asserts it would have been obvious to use the thermoelectric element taught by Fujita in the fuel-cell stack taught by Reiser. Applicants disagree and respectfully point out that when the thermoelectric element of Fujita is added to the *outside* heat exchanger of Reiser, then it does not result in the thermoelectric module in ***conductive*** thermal contact with a bipolar plate of the heat source because then the thermoelectric module would be in ***convective*** thermal contact with a fuel-cell.

Therefore, it is respectfully submitted that Reiser in view of Fujita does not disclose or suggest every feature recited in Claim 11. Thus, it is respectfully requested that the rejection of Claims 10 and 11, and all other claims dependent thereon, as unpatentable over the combination of Reiser and Fujita be withdrawn.

With respect to the rejection of Claim 13 under 35 U.S.C. § 103(a) as being unpatentable over Reiser in view of Fujita, and in further view of Ghamaty, this rejection is respectfully traversed.

The Office Action asserts on page 7, lines 18-20 that Ghamaty teaches thermoelectric elements, N- and P-type samples consisting of silicon and germanium alloys with the N-type doped with phosphorous and the P-type doped with boron. However, Ghamaty does not disclose or suggest a plurality of thermoelectric modules in thermal connection with a fuel-cell. As such, Ghamaty does not make up for the deficiencies of Reiser and Fujita. Accordingly, withdrawal of the rejection of Claim 13 under 35 U.S.C. § 103(a) based on Reiser in view of Fujita, and in further view of Ghamaty is respectfully requested.

With respect to the rejection of Claim 14 under 35 U.S.C. § 103(a) as being unpatentable over Reiser in view of Fujita, and in further view of Szabo de Bucs, this rejection is respectfully traversed.

The Office Action asserts on page 8, lines 15-17 that Szabo de Bucs teaches a thermoelectric device whose legs are interconnected by contact bridges 2, 3 composed of an alloy of silicon with molybdenum. However, Szabo de Bucs does not disclose or suggest a plurality of thermoelectric modules in conductive thermal connection with a fuel-cell. As such, Szabo de Bucs does not make up for the deficiencies of Reiser and Fujita. Accordingly, withdrawal of the rejection of Claim 14 under 35 U.S.C. § 103(a) based on Reiser in view of Fujita, and in further view of Szabo de Bucs is respectfully requested.

With respect to the rejection of amended Claims 17-18 under 35 U.S.C. § 103(a) as being unpatentable over Reiser in view of Fujita, this rejection is respectfully traversed

Amended Claims 17-18 recite, in part, "A method for partial recuperation of thermal energy from a fuel-cell stack, comprising: ... circulating a cooling fluid in the interior of the fuel-cell stack... to place the cooling fluid in thermal contact with a first side of a plurality of thermoelectric modules attached to the fuel-cell stack."

Applicants respectfully submit the cited references do not discuss a plurality of thermoelectric modules attached to the fuel-cell stack. Accordingly, withdrawal of the rejection of Claims 17-18 under 35 U.S.C. § 103(a) based on Reiser in view of Fujita is respectfully requested.

New Claims 19-26 are added by the present amendment. Support for new Claims 19-26 can be found in the original specification, for example, at page 2, lines 3-11, at page 2, lines 18-22, at page 2, line 27 to page 3, line 2, at page 3, lines 9-12, at page 3, lines 27-28, at page 4, lines 2-9, at page 5, lines 8-9, in Figure 1, and in Claims 10-18. Thus, it is submitted that no new matter is added.

New independent Claim 19 recites, in part, "[a] first thermoelectric layer is disposed between and attached to the first plate and the first fuel-cell." The applied art does not discuss this feature. Instead, Fujita discusses generating electricity by attaching a

thermoelectric element to a heat exchanger that supports a SOFC fuel-cell, but not to a thermoelectric element within a fuel-cell stack.[12] The instant invention discusses thermoelectric modules within a fuel-cell stack and heat exchangers outside the fuel-cell stack.[13] Accordingly, it is respectfully submitted that Claim 19 further patentably defines over the applied art.

New Claim 20 recites, in part, a cathode bipolar plate having a first engraved duct to carry the oxidizer. The applied art does not teach this feature. Reiser merely discusses channels 32a within a separator plate 24a to carry an oxidant.[14] Accordingly, it is respectfully submitted that Claim 20 further patentably defines over the applied art.

New Claim 21 recites, in part, a first plate having a plurality of cooling fins extending into an internal duct passageway. The applied art does not teach this feature. Reiser merely discusses passageways 62 for cooling tubes 60 within a separator plate 24a.[15] Accordingly, it is respectfully submitted that Claim 21 further patentably defines over the applied art.

New Claims 22-24 recite, in part, a thermoelectric module layer comprising a pair of dissimilar conductive materials and each of the dissimilar materials include a heat conductor end configured to be in conductive thermal contact with the second anode surface. The applied art does not teach nor disclose this feature. Accordingly, it is respectfully submitted that Claims 22-24 further patentably define over the applied art.

New Claim 25 recites, in part, a thermoelectric module layer comprising a pair of dissimilar conductive materials and each of the dissimilar materials include a heat conductor end configured to be in a conductive thermal contact with the first cathode surface. The applied art does not teach this feature. Accordingly, it is respectfully submitted that Claim 25 further patentably defines over the applied art.

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[12] See Fujita, ¶ 24 English translation.
[13] See original specification, page 4, lines 13-15.
[14] See Reiser at Figure 3.
[15] See Reiser at Figures 2-3.

New Claim 26 recites, in part, the first electric power, the second electric power, and the third electric power are supplied to energize a motor vehicle. The applied art does not teach this feature. Accordingly, it is respectfully submitted that Claim 26 further patentably defines over the applied art.

Consequently, for the reasons discussed in detail above, no further issues are believed to be outstanding in the present application, and the present application is believed to be in condition for formal allowance. Therefore, a Notice of Allowance is earnestly solicited.

Should the Examiner deem that any further action is necessary to place this application in even better form for allowance, the Examiner is encouraged to contact the undersigned representative at the below listed telephone number.

Respectfully submitted,

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CO-GENERATION OF ELECTRICITY BY THE SEEBECK EFFECT WITHIN A FUEL CELL

BACKGROUND

FIELD OF THE INVENTION

The present invention relates to a fuel-cell stack and to a method for recuperation of thermal energy as electrical energy.

DESCRIPTION OF THE RELATED ART

Fuel-cell stacks permit direct conversion of the free energy of a chemical oxidation-reduction reaction to electrical energy and, in the motor vehicle field, they appear to be one of the most promising current technologies for satisfying the European requirements of pollution and consumption reduction.

However, the disadvantage of the system lies in the management of the thermal energies. In fact, the cooling circuit of a fuel-cell stack must evacuate approximately 1.5 times as much thermal energy as the electrical power produced. This constitutes a large energy loss, which greatly reduces the efficiency of the system.

It therefore is advantageous to obtain means capable of utilizing the thermal power discharged by the fuel-cell stack, by transforming it into energy that the vehicle can use.

German Patent DE 19825872 describes a fuel-cell stack of the high-temperature SOFC type enclosed in a double-wall encapsulation composed of a hot wall in contact with the cell stack and a cold wall cooled by any appropriate medium. Between these two walls there are disposed thermoelectric elements that produce an electric current by virtue of the temperature difference to which they are exposed between these two walls. Since the thermal energy recuperation system is located outside the fuel-cell stack, the observed heat losses make it impossible to obtain an advantageous efficiency with this known device.

SUMMARY

The object of the invention is a fuel-cell stack comprising means for recuperating, in the form of electrical energy, the thermal energy produced by the cell stack, limiting the energy losses as much as possible and making it possible to obtain an improved efficiency, as well as a method for recuperation of thermal energy in the form of electrical energy in such a fuel-cell stack.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows an assembly of two cells of a fuel-cell stack mounted on board a vehicle with proton exchange membrane technology.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The fuel-cell stack according to the invention comprises at least two elementary cells, disposed in facing relationship, for an exothermic combustion reaction constituting a heat source, and an internal duct formed between the cells for circulation of a cooling fluid constituting a cold sink. This cell stack comprises a plurality of thermoelectric modules, each comprising a pair of elements of two conductive materials of dissimilar nature. A first end of each pair is in thermal contact with the heat source or the cold sink, while the second end of each of the elements of the said pair is in contact with the other source or sink, and is electrically connected to a neighboring module.

By virtue of this plurality of thermoelectric modules disposed in the very interior of the cell stack, the thermal energy produced by the cells of the cell stack is converted to electrical energy, while minimizing the energy losses of the system. In addition, this embodiment is simpler to implement and is less costly.

Preferably, the fuel-cell stack used is a membrane cell stack of the PEM type.

In an advantageous embodiment, the thermoelectric module is composed of a pair of conductive materials connected at one of their ends by a thermally and electrically conductive connection in thermal contact with the heat source, and connected to one another at their free ends by a thermally and electrically conductive connection in thermal contact with the cold sink.

In a preferred embodiment, the two conductive materials of the thermoelectric modules are semiconductors, one of P type, or in other words a positively doped semiconductor, and the other of N type, or in other words a negatively doped semiconductor.

In an advantageous embodiment, the N-type materials are alloys of silicon and germanium doped with phosphorus. The P-type materials are alloys of silicon and germanium doped with boron.

Advantageously, the conductive connections connecting the ends of the materials are composed of molybdenum electrodes.

In a preferred embodiment, the last thermoelectric module of an assembly disposed along a first elementary cell is electrically connected in series or in parallel with the first thermoelectric module of an assembly disposed along a second elementary cell.

Advantageously, a plate forming a wall equipped with fins is disposed on the external surface of an assembly of thermoelectric modules, constituting a boundary of the cooling duct, the fins being disposed on the same side as the cooling duct in order to favor heat exchange.

The method of the invention for recuperating, in the form of electrical energy, thermal energy originating from a fuel-cell stack utilizes, as cold sink, a cooling fluid circulating in the interior of the fuel-cell stack between two elementary cells of that same cell stack constituting the heat source. This cooling fluid is placed in thermal contact with a plurality of thermoelectric modules. Thus the electrical energy generated by the Seebeck effect is recuperated.

Preferably, the method of the invention uses a membrane cell stack of PEM type as the fuel-cell stack.

Advantageously, this method implements two-phase cooling of the cell stack.

The invention will be better understood by studying the detailed description of a practical example, in no way a limitative example, illustrated by FIG. 1, very schematically showing two elementary cells of a fuel-cell stack according to the invention.

FIG. 1 shows an assembly 1 of two cells of a fuel-cell stack mounted on board a motor vehicle with PEM (proton exchange membrane) technology. The fuel-cell stack is composed of a succession of elementary electricity-producing cells. Only two elementary cells 2 and 3 are shown in FIG. 1. These elementary cells 2 and 3 are composed of two bipolar plates 4 and 5 separated by a porous membrane 6. On the surface of bipolar plate 4 there are engraved ducts 7, in which there circulates oxygen 8. Similarly, on the surface of bipolar plate 5 there are engraved ducts 9, in which there circulates hydrogen 10. The oxygen and hydrogen circulate perpendicularly to the plane of the figure. Since the reaction that takes place in this cell is exothermic, the temperature of bipolar plates 4 and 5 tends to rise. It is therefore necessary to cool them in order to evacuate the calories.

The two producing cells 2 and 3 define an internal cooling duct 11, in which there circulates a heat-transfer fluid 12 that evacuates the calories outside the cell stack. The heat-transfer fluid circulates in a direction perpendicular to the plane of FIG. 1. At the outlet of the cell stack, fluid 12 is cooled by means of heat exchangers not illustrated in the figure, and is reintroduced in cold condition at the inlet of the fuel-cell stack.

The means that permit conversion of the thermal energy into electrical energy comprise a plurality of thermoelectric modules 13. This assembly of thermoelectric modules is disposed between bipolar plate 5 of elementary cell 2 constituting the heat source and

internal cooling duct 11, in which there circulates cooling fluid 12, which constitutes the cold sink. These modules are composed of two conductive materials 14 and 15 of dissimilar nature, connected at one of their ends by a thermally and electrically conductive connection 16 in thermal contact with heat source 5. At their free ends the thermoelectric modules are connected in series by a thermally and electrically conductive connection 17 in thermal contact with cold sink 12.

The pairs of materials 14 and 15 are matched to the temperature level of the cell stack and of the cooling circuit.

As an example, the conductive materials that constitute the thermoelectric modules are semiconductor materials. Of dissimilar nature, one is P-type, or in other words a positively doped semiconductor, and the other is N-type, or in other words a negatively doped semiconductor. The P-type semiconductors are, for example, alloys of silicon and germanium doped with boron. The N-type semiconductors are, for example, alloys of silicon and germanium doped with phosphorus.

Conductive connections 16 and 17 connecting the ends of materials 14 and 15 are composed of molybdenum electrodes.

By means of connections A, B or C, the last thermoelectric module of an assembly disposed along a first elementary cell is electrically connected in series or in parallel with the first thermoelectric module of an assembly disposed along a second elementary cell.

A plate 18 forming a wall equipped with fins 19 is disposed on the external surface of the assembly of thermoelectric modules on the same side as internal cooling duct 11, the fins being disposed on the same side as internal cooling duct 11. The addition of fins to the wall makes it possible to improve heat exchange.

In other words, bars of conductive materials 14 and 15 of dissimilar nature are disposed alternately as crosspieces between an elementary cell 2 or 3 of a fuel-cell stack 1 and internal cooling duct 11 adjacent to that cell 2 or 3. These bars of conductive materials 14 and 15 are connected alternately in pairs by thermally and electrically conductive connections, some 16 along elementary cell 2 or 3 constituting the heat source and the others 17 along internal cooling duct 11, cooling fluid 12 constituting the cold sink. This succession of bars of conductive materials constitutes the plurality of thermoelectric modules 13.

In a preferred embodiment, a wall 18 composed of fins 19 is disposed perpendicularly to the succession of bars of conductive materials 14 and 15, along conductive connections 17, constituting a boundary of internal cooling duct 11.

ABSTRACT

~~The method of implementation advantageously utilizes two-phase cooling of the fuel-cell stack. In this type of cooling, the fluids evacuate the heat by evaporating at constant temperature. It will be possible to choose this temperature as a function of the desired operating temperature of the cell stack, in order to optimize the recuperated power. For this purpose, the heat-transfer fluid will be chosen as a function of its temperature.~~ A fuel-cell stack is presented that may include two elementary cells disposed in a facing relationship and which produce electric energy and heat. An internal duct is formed between the elementary cells for cooling fluid circulation. A plurality of thermoelectric modules are in thermal contact with one of the elementary fuel-cells and the cold sink and the modules produce additional electrical energy. Each of the thermoelectric modules comprises a pair of elements made of two materials of dissimilar nature.